

### ME 321: Fluid Mechanics-I

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Lecture - 01 (12/04/2025) Fluid Dynamics: Introduction

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Fluid dynamics is the science dealing with the motion of fluids. Fluids, unlike solids, cannot assume a fixed shape under load and will immediately deform (liquid and gas).

Fluid dynamics can be studied by *focusing on a particle* (Lagrangian approach) or *focusing at a point in fluid (Eulerian approach)* to understand the nature of flow. It covers a vast array of phenomena that occur in nature, modern engineering inventions, biology, life sciences, and so on.

**Geophysical (atmospheric) fluid dynamics** 





Tornado

Hurricane (2023: Midhili, Hamoon)





#### Viscous droplet umbrellas Two axial-aligned consecutive droplets impacting a bath of a fluid can form an 'umbrella' film when properly spaced. The first droplet forms a cavity and then a Worthington jet which the second droplet falls onto; spreading into a thin film with multiple droplets at the edge, resembling a handle and umbrella as marked in a). Images of the event are captured by two flashes that stop the motion of an open shutter of an SLR camera. The technique is as old as Worthington's first droplet images and reminiscent of H.E. Edgerton's famous artwork 'Milk drop coronet'. Here, the bath (red) and droplets (white) are the same fluid; a mixture of water, acrylic paint (1 wt%) and cosmetic b Xanthan gum. The Xanthan gum increases the viscosity of the droplet. As the percentage is increased, the thin film stretches extensively before rupture and the rim droplet formation is suppressed as marked in b). The large photograph reveals a mixture of white and red fluid in the thin sheet and the thicker rim (XG 0.01 wt%), with capillary waves apparent near the edge. The simplistic droplet impact Worthington introduced and Edgerton popularized continue to provide rich physics and beautiful imagery. XG 0 wt%



wt% 0.



P0024: Viscous droplet umbrellas (73th Annual Meeting of the APS Division of Fluid Dynamics 2020)

Saliva particle transport during normal breathing from nose and mouth simultaneously, which are shown from sagittal plane and top plane, at t=90 s. The effect nose's cross flow is evident in the bending of the mouth's jet like flow. Also, each vortex ring undergoes a rolling up process which is due to a high velocity region in the lower section of the vortex ring.

Trajectories of saliva particles on a 5 cm thick layer around the sagittal layer around during normal breathing through nose and mouth simultaneously, at t=90 s. Each color denotes to a breathing cycle. We can capture the key material line in the air-saliva mixture. The new particles in the breathing cycle travel through the stable manifold until they reach the forefront of the vortical structure.

# P0012: Saliva particles transport during normal breathing through mouth and nose (76th Annual Meeting of the APS Division of Fluid Dynamics 2023)







P0015: Numerical Schlieren of the X-59 QueSST (74th Annual Meeting of the APS Division of Fluid Dynamics 2021)

The X-59 QueSST (Quiet SuperSonic Technology) is a partnership project between NASA and Lockheed Martin with the primary objective of solving one of the most persistent challenges of supersonic flight: the sonic boom. Mach 2.3

**Shocking Interactions** 

nic flows, shockwave boundary layer interactions are a of technical uncertainty and risk. Such interactions create regions of intense heating and fluctuating pressure. These phenomena are when shockwaves interact with transitional boundary layers which are alread ntermittent state change. Understanding the dynamic behavior of ons is a vital need for the development of emerg

In this schlieren image, a transitional shockwave boundary layer interaction has been generated using a 1/8-inch diameter cylinder on a 20-degree half-angle cone ach 2.3 freestream. Near the cone surface, the bow shock of the cylinder cts with the boundary layer causing a bifurcation of the shockwave and ion in the underlying region. Due to the transitional nature of the ary layer, the interaction is unsteady, and the extent of separation changes in response to the state of the incoming boundary layer. The resultant local y thermal and mechanical loads are responsible for some of the most ntense surface conditions experienced by the vehicle surface. Also, visible in this image are several shock-shock interactions where the cone and cylinder bo

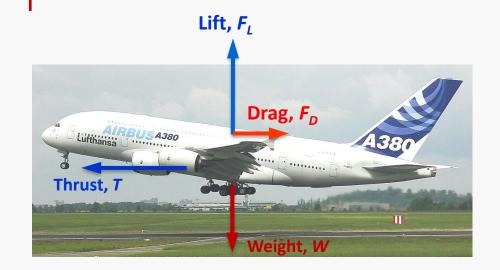
Zane M. Shoppell, Kenneth R. Langley, and John D. Schmiss

University of Tennessee Space Institute IORIZON Research Group

P0040: Shocking Interactions (75th Annual Meeting of the APS Division of Fluid Dynamics 2022)







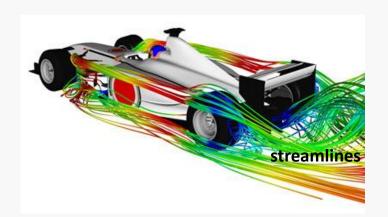
Airplane aerodynamics



F-16 Fighter plane



Rocket launching (SpaceX Falcon 9)



Racing car aerodynamics



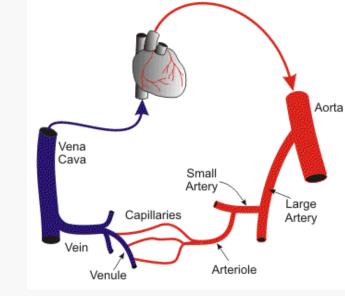
High speed train (320 km/hr)



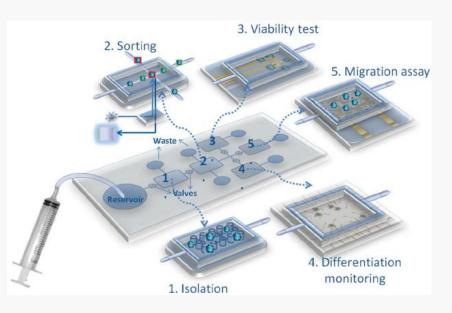
Offshore wind turbines







#### **Blood flow through vascular network**



#### Lab-on-a-chip (LoC) microfluidic device





Flying of birds (Biomimetics)



<u>Micro Unmanned Air Vehicle</u> (µUAV)

### Fluid Flow at Microscale



At the **microscale**, the interaction between the fluid and solid wall is different than that at the **macroscale**. Fundamental studies have shown that the **continuum hypothesis** may not be valid at microscale and some specific effects may be present that can alter the fluid flow and heat transfer characteristics significantly.

At the microscale, surface area to volume ratio is much larger, which results in

- increased surface forces, which may produce large pressure drops,
- Increased viscous dissipation (small length scale, large velocity gradient);
- **decreased inertial forces**, which allows diffusion and conduction processes to become relatively more significant;
- increased heat transfer, which may lead to variable fluid properties and
- **thermal creep** (The thermal creep is defined as the macroscopic movement of rarefied gas molecules induced by a temperature gradient from lower to higher temperature zone).

Therefore, these effects need to be considered to predict the fluid flow and heat transfer characteristics.



### **AI in Fluid dynamics**



#### 🔶 Al Overview

Al, particularly machine learning, is transforming fluid dynamics by enhancing computational fluid dynamics (CFD), optimizing flow control, and improving simulation accuracy. Al techniques are used to accelerate CFD simulations, analyze real-time flow, and even control complex fluid interactions. This integration allows for more efficient design of aerodynamic models, better turbulence modeling, and advancements in fields like weather forecasting and energy systems.

#### Elaboration:

#### Accelerating CFD Simulations:

Al, especially machine learning algorithms, can significantly reduce the computational time required for CFD simulations by learning patterns from large datasets and making predictions more efficiently.

#### Improving Simulation Accuracy:

Al models can be trained on experimental data or more accurate CFD simulations to refine models and improve the prediction of complex fluid flow behaviors.

#### **Optimizing Flow Control:**

Al techniques like reinforcement learning can be used to develop and control fluid flow, for example, in boundary layers to reduce drag or improve efficiency.

#### **Real-time Flow Analysis:**

Al models can be deployed in real-time to analyze CFD simulations and provide feedback during testing or actual operation, enabling more dynamic and responsive design optimization.

#### Applications:

- Aerodynamics: AI can be used to predict drag coefficients, optimize airfoil shapes, and improve the performance of aircraft and other vehicles.
- Turbulence Modeling: AI can help develop more accurate and efficient turbulence models, which are crucial for simulating complex fluid flows.
- Weather Forecasting: Al algorithms can be used to improve the accuracy of weather models and predict weather patterns more reliably.
- Energy Systems: AI can optimize the design of wind turbines, hydraulic structures, and other energy systems, leading to increased efficiency.



Source: Al overview in Google search



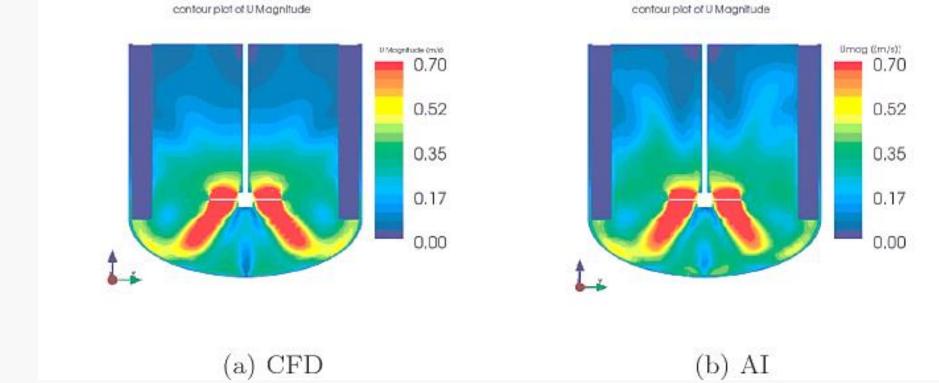
| Approach                   | Accuracy         | What is needed?   | Gives<br>result   |
|----------------------------|------------------|---|-------------------|
| experimental testing       | Very High        | Physical prototype<br>Laboratory                              | in days           |
| CFD                        | High / Very High | Physical models<br>Skills (experience)<br>HPC or cloud rental | in hours          |
| human brain                | Biased           | Skills (experience)   | in seconds        |
| Machine<br>(Deep) Learning | High / Very High | Data from CFD /<br>experimental testing                       | in (milli)seconds |

A comparison of various engineering prediction methods in terms of accuracy of prediction, needed resources and speed of prediction

https://www.neuralconcept.com/post/applying-machine-learning-in-cfd-to-accelerate-simulation







https://link.springer.com/chapter/10.1007/978-3-030-77964-1\_29





- Fundamental concept of fluid as a continuum; Fluid Properties. (MMR)
- Fluid Statics: basic hydrostatic equation, pressure variation in static incompressible and compressible fluids; Manometers; Forces on submerged plane and curved surfaces; Buoyant force; Stability of floating and submerged bodies; Pressure distribution of a fluid in rotating and accelerating systems. (MMR)
- Fluid dynamics: Concepts of system and control volume: Continuity, momentum and energy equations and their applications; Introduction to Navier-Stokes equations. (MTH)
- Pressure, Velocity and Flow measurement devices. (MTH)
- Introduction to inviscid incompressible flow. (<u>MMR</u>)





### Text books:

- F. M. White, Fluid Mechanics, 7<sup>th</sup> Edition, 2011, ISBN: 978-007-131121-2.
- M.C. Potter, D.C. Wiggert, Mechanics of Fluids, 3<sup>rd</sup> Edition, 2010, ISBN: 978-0-495-43857-1.
- Class lectures will be available at http://toufiquehasan.buet.ac.bd

### **Reference books:** (for further reading)

- i. Munson, Okiishi, Huebsch, Rothmayer, Fundamentals of Fluid Mechanics, 7<sup>th</sup> Edition, 2013, ISBN: 978-1-118-18676.
- ii. Fox and McDonald, Introduction to Fluid Mechanics, 9<sup>th</sup> Edition, 2015, ISBN: 978-1118912652.
- iii. J. F. Douglas, J. M. Gasiorek, J. A. Swaffield, L. B. Jack, Fluid Mechanics, 5<sup>th</sup> Edition, 2005, ISBN- 978-0-13-129293-2.







### **Outcome Based Education (OBE)**

- What is OBE?
  - a concept/framework for educational programs that focuses on <u>what the student</u> <u>should be able to do</u> at the end of a course/program rather than what he/she is taught
- **OBE** has been adopted by most well-recognized Accreditation bodies to improve higher educational programs continuously
- **OBE** is being adopted in many of the present day textbooks as well.





## **Complex Engineering Problems**

| Engineers     | ability to solve Complex engineering problems* |  |
|---------------|--|--|
| Technologists | ability to solve Broadly defined problems**    |  |
| Technicians   | ability to solve Well-defined problems***      |  |

According to \*Washington Accord, \*\*Sydney Accord and \*\*\*Dublin Accord





| CO No. | CO Statement   |
|--------|--|
| CO 1   | <b>Explain</b> the properties of fluids such as viscosity, vapor pressure, surface tension, and compressibility. |
| CO 2   | <b>Determine</b> the pressure in a fluid system using the concept of manometry.                                  |
| CO 3   | <b>Calculate</b> the hydrostatic pressure force on a plane and curved submerged surface.                         |
| CO 4   | <b>Apply</b> the continuity, momentum and energy equations to solve fluid dynamic problems.                      |
| CO 5   | Analyse the flow measurement devices.  |
| CO 6   | <b>Apply</b> the concepts of stream function and velocity potential in simple inviscid incompressible flows.     |

